Title: Searching for Dark Photon and Dark Higgs Particles with the SeaQuest Spectrometer at Fermi laboratory
Funding Source: LANL LDRD Office
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The SeaQuest/E906 experiment at Fermi laboratory is primarily designed to study the quark and anti-quark structure of the nucleon and its modification inside nucleus by measuring high-mass Drell-Yan production in p+p and p+A collisions with various nucleus targets. The experiment uses a 120 GeV/c proton beam from the Fermi lab main injector. Figure 1 shows the SeaQuest/E906 spectrometer consisting of two dipole magnets and four tracking stations. The target is about 6% of nuclear interaction length, so most of protons interact with the beam dump which provide a large number of p+Fe collisions. This condition is suitable for a parasitic run to explore the dark sector named SeaQuest/E1067 in high-energy p+A collisions with 1.44×10^{18} POT (considering the upcoming E1039 experiment).

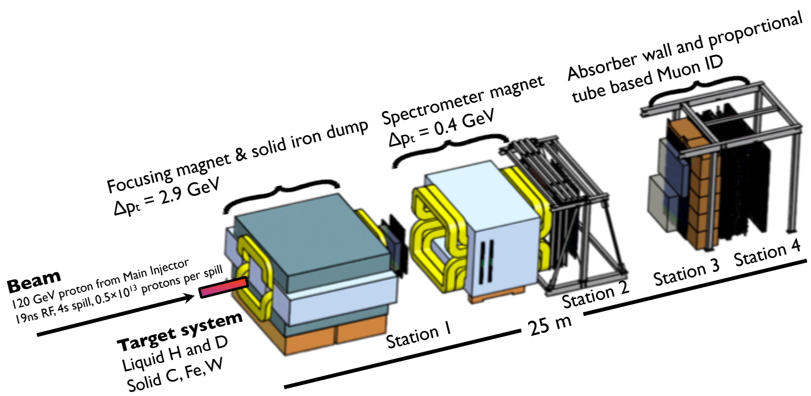

Figure 1: The SeaQuest/E906 spectrometer.

One of channel to access the dark sector is so called dark photon (A') which is expected to interact feebly with the normal matter by kinematic mixing with the regular photons as shown in the left Feynman diagram of Fig. 2. According to the dark matter phenomenology models, the mass of dark photon is likely to be in between 1 MeV/c^2 and 10 GeV/c^2, and the current E906 spectrometer has an excellent capability to measure dimuons in this mass range. Another channel is dark Higgs (ϕ) which can be obtained from the electroweak symmetry breaking of the standard model Higgs boson as shown in the right Feynman diagram of Fig. 2. These dark photon and Higgs are feebly interaction with the normal matter, the decay vertex will be largely displaced from the production vertex. Due to the 5 m length of solid iron beam dump/magnet, most of particles other than neutrinos and muons are stopped before penetrating 1/3 of the beam dump.

Therefore, the displaced decay vertex can help us to distinguish between SM particles and dark photons (Higgs).

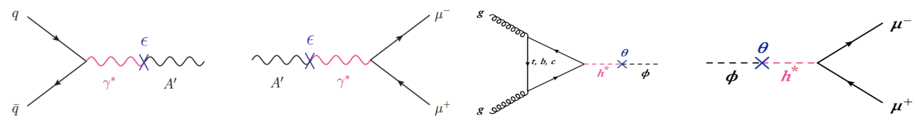

Figure 2: Feynman diagrams for production of dark photon (left) and dark Higgs (right) and their decay into muon pairs.

In order to reconstruct the displaced decay vertex and reject background events, a moderate upgrade of trigger system has been proposed. From the initial studies, a scintillating-strip tracking detector located in between the tracking station 1 and 2 could satisfy the requirements. The trigger station 1 locating at upstream is consisting of 4 boxes, and each box contains 80 scintillator bars ($1{\times}1{\times}80$ cm^3). In case of the trigger station 2 in front of the tracking station 2, each box includes 50 scintillator bars ($1.5{\times}1.8{\times}100$ cm^3). In each scintillator bar, two wave-length shifting fibers are inserted to collect light, and the polished end of these fibers are in contact to a SiPM and preamp card. From the test with a prototype, the efficiency is higher than 96%. There is also an calibration system with pulser board of red LEDs to check whether each channel is working. An signal input fiber connects to the coupler and distribute light to 19 clear fibers, and each clear fibers is inserted into each scintillator bar. Each trigger station is composed of 4 boxes of 50 or 80 bars. Figure 3 shows inside the box of trigger station 1 which is built at LANL. The left figure shows the entire box, and the right figure shows a closer view of fibers and cables connection. These detectors have been built during the last few months at LANL, and they are now under commissioning at Fermi lab. By incorporating with the existing tracking station 4, ~ 30 cm of z-vertex resolution for dimuons of $0.2 < M < 2$ GeV/c^2 can be achieved based on simulation study.
The data taking of SeaQuest/E1067 will be finished in this summer, and the trigger detector commissioning and initial data taking will be done from now to the end of the data taking. After that, another experiment (E1039) will continue on running a new physics program of polarized proton target with the current SeaQuest dimuon spectrometer for 2 years. Based on the beam condition of the SeaQuest operation, the expected POT is about 1.44×10^{18}. Figure 4 shows projected sensitivity for dark photon (left) and dark Higgs (right) search. In the plot of dark photon search, the red area is from the existing dimuon spectrometer, and dark photon could be produced via kinematic mixing with the SM photon from ϕ^0 and η decay. The magenta area is a projection of electron decay channel with possible detector upgrades. The right panel of Fig. 4 shows a preliminary study for dark Higgs with two cases of luminosity. The sensitivity area expected from the E1067 is a quite unique parameter space compared other experiments.

Figure 3: A side view of the entire box of trigger station 1 including all components (left) and a closer view of fibers and cables connection.

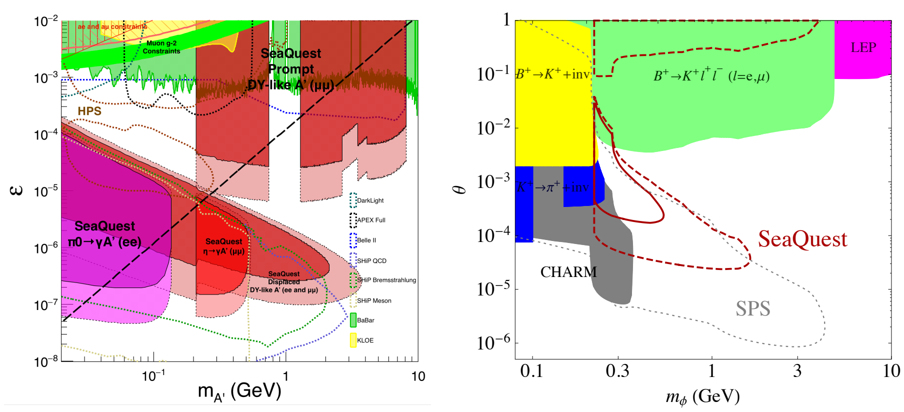

Figure 4: The projected 95% sensitivity on dark photon (left) and dark Higgs (right) searches in the E906/E1036 experiments.